# Revision of EBG Metamaterials and Active Antennas

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***Abstract*—This review of Electromagnetic Band Gap (EGB) metamaterials and steering integrated antennas was carried out in IMST GmbH under a Short Term Scientific Mission. This activity is in line with Coordinating the Antenna Research in Europe (CARE). The aim is to identify the newest trends, and suggest novel solutions and design methodologies for various applications.**

## I. Introduction

Starting from the results achieved by the ACE Network of Excellence (from 2004 to 2008), CARE (introduced in 2009), continues and reinforces the collaboration among the European Institutions involved in antenna research. In CARE, the level of cooperation reached in ACE will be sustained and improved by students and researchers secondment, best practices sharing, industrial training and dissemination, by publications and conferences.

This paper gives an overview of the EBG metamaterials theory in section II [1]. The section III is devoted to EBG applications. In section IV the main problems of steering integrated antennas are presented. Finally, in section V the conclusions are drawn.

## II. EBG Theory

Electromagnetic Band Gap (EBG) based on Frequency Selective Surfaces (FSS) [2] are one type of metamaterials with electrical properties [3].

EBG technique appears as an application of truncated frequency selective surface (FSS) [4]. These structures consist of an array of metal protrusions on a flat metal sheet and can be visualized as mushrooms protruding from the surface. When the period is small compared to the wavelength of interest, it is possible to analyze the material as an effective medium, with a surface impedance. These "mushrooms" present very high impedance for vertical an horizontal modes at certain frequencies.

These structures can be analyzed as resonant LC circuits, in which the capacitance is provided by the proximity of the metal plates:

$$C = \left[\frac{w\varepsilon_0(\varepsilon_{eff})}{\pi}\right]\cosh^{-1}\left(\frac{2w}{g_0}\right) \tag{1}$$

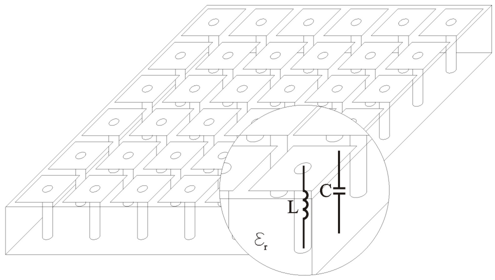



Fig. 1. High impedance surface and its model with parallel resonant LC circuit.

and the inductance is related to the thickness of the structure:

$$L = \mu_0 t \tag{2}$$

Therefore, the surface impedance is given by the following expression:

$$Z_s = \frac{j\omega L}{1-\omega^2 LC} \tag{3}$$

The resonance frequency of the circuit is given by:

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{4}$$

Below resonance, the surface is inductive meanwhile above resonance, the surface is capacitive. Near $\omega_0$, the surface impedance is much higher than the impedance of free space [4].

## III. EBG applications

Among others, EBG structures are used as ground planes emulating Artificial Magnetic Conductors (AMC) in a narrow frequency range. EBG are used also to reduce the mutual coupling between elements.

### A. EBG Ground plane

EBG structure has one important feature: the in-phase reflection coefficient for plane waves. This property can be used to design low-profile wire antennas [5]. The low-profile

TABLE I
COMPARISON OF PEC, PMC, AND EBG GROUND PLANES FOR LOW PROFILE ANTENNA DESIGNS.

| Ground plane | Reflection phase | Comments |
|---|---|---|
| PEC | $180°$ | Reverse image. |
| PMC | $0°$ | Mutual coupling. |
| EBG | Varies from $180°$ to $-180°$ with frequency | Suitable frequency band. |

design usually refers to the antenna structures whose height is less than one-tenth. In chapter 12 of [6], a comparison between PEC, PMC, and EBG ground planes is carried out. The conclusions are drawn in Table I.

In [7] EBG ground plane is used to reduce the effect of multipath by blocking the propagation of surface waves and cross polarization component in a low profile GALILEO antenna. Its performance is similar to a classical choke ring antenna, but with the advantage of low weight and low profile.

### B. Filters

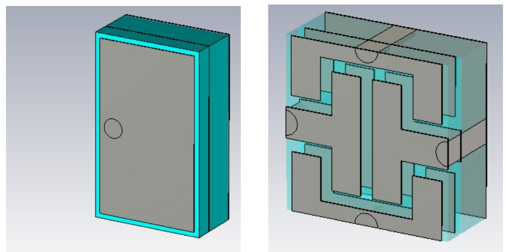
Thanks to its frequency selective feature, this EBG structure can be used as a filter. By applying three elements as a ground plane for a microstrip line, in [8] isolation higher than 55 dB in the first frequency band (2.1 GHz) and 40 dB in the second one (2.45 GHz) are achieved.

### C. Mutual coupling reduction

Patch antennas are found to have very strong mutual coupling due to the pronounced surface waves on a thick and high permittivity substrates. However, in order to reduce antenna size and bandwidth enhancement there is no other option. In [9], four columns of EBG patches are inserted between the antennas in a $\epsilon_r = 10.2$ and thickness ($h = 2$ mm) substrate. Finally 8 dB of reduction are obtained. In array applications where the separation between elements is $0.5\lambda$ in order to avoid grating lobes, the available space is not enough to introduce four columns of EBG structures. In [10] different substrates are combined, radiating elements are suspended over a thick foam layer in order to increase the bandwith, meanwhile EBG structures are printed in a thin high permittivity substrate for size reduction and surface wave suppression. In [11] by using edge-located vias the size of mushroom-type EBG is reduced by $20\%$. Among other strategies in [12] a fork shape is used. The area occupied by the fork-like structure is less than $40\%$ of the mushroom-like structure. Besides, Microelectromechanical Systems (MEMS) are used and reconfigurable stop band is obtained.

Another technique studied is metal strips. Basically, the idea is to combine the EBG concept with soft surfaces. A comparison of bandgaps of mushroom-type EBG surface and corrugated and strip-type soft surfaces is shown in [13]. This stripe-type is used in [14] and in [15] to reduce mutual coupling. Finally, dual band planar soft surfaces are developed in [16], two sizes of strips are mixed in order to get dual forbidden band.

New solutions for patch size reduction are proposed. In order to maintain the working frequency with the same substrate thickness, the only parameter available is the capacitance $C$. In order to increase this parameter a multilayered structure is presented in Fig. 2(a) and Fig. 2(b) [17].



(a) Multilayered patch-shape (b) Multilayered H-shape

Fig. 2. Multilayered mushroom-type solutions.

## IV. STEERING APPLICATIONS

The antenna array concept arises due to the necessity of getting higher directivity. By changing the phase feeding of the array elements the radiation pattern can be steered in the desired direction [18] without moving the antenna physically.

### A. Active networks

This kind of feeding can be done through active networks such as phase shifters or microelectromechanical systems (MEMS). Those systems have high complexity but high flexibility and features. In [19] MEMS are used in an antenna array front end at 24 GHz. The aim of the project is to combine MEMS with monolithic microwave integrated circuits (MMIC), this system presents low insertion loss, large bandwidth, and good linearity over frequency. In [20] four elements array is fed by coplanar transmission lines (TL). Using MEMS, those TLs change their capacity and propagation velocity, therefore the radiating elements can be fed with the desired phase shift. In [21], a complex system of 156 radiating elements in Ku band is presented. This system is constructed in Low Temperature Co-Fired Ceramic (LTCC) technology, it has linear polarization with tracking, a scan range from $20°$ to $60°$ in elevation from horizon and $0°$ to $360°$ in azimuth. The antenna size is 20 cm x 20 cm x 2 cm, optimum for car integration. In [22]-[23] the Smart Antenna Terminal (SANTANA) is presented. The system works in Ka-band for reception (RX) and transmission (TX). The uplink frequency is 29.75 GHz and the downlink frequency is 19.95 GHz, this system has the capability of electronic steering in azimuth and elevation and the radiating element is realized in a 16 multilayered LTCC structure. L-band phased array for maritime satcom is shown in [24]. This antenna consists of 26 patch elements that are mounted on a soccer-like spherical aperture. This design is an innovative and powerful alternative to current mechanically steered systems. The last example, antenna GEODA-GRUA [25] is one conformal adaptative antenna designed for satellite communications. Operating at 1.7 GHz with circular polarization, it is possible to track and communicate with several satellites at once being able to receive signals in full azimuth and within the range of 5º to broadside elevation. The antenna is composed of 2700 radiating elements based on a set of 60 triangular arrays that are divided in 15 subarrays of 3 radiating elements.

### B. Passive networks

Another beam control option is passive networks. Butler matrix network [26] consists in $2^n$ inputs, $2^n$ outputs, $2^{n-1}\log_2 2^n$ hybrid couplers, crossovers and phase shifters. The function of a Butler matrix is to combine signals in phase going or coming from an antenna array. It produces $2^n$ beams with constant angular separation. Blass matrix network [27] has two groups of transmission lines which are interconnected through hybrid couplers. The path difference, is the clue in order to control the beam steering. This solutions do not have so good features but are cheaper solutions. In [28] a dual circular polarized steering antenna for satellite communications in X band is presented. This antenna has the following capabilities: broadband capacity (7.25-8.15 GHz) 15%, dual circular polarization (RHCP and LHCP, interchangeable for TX and RX), good axial ratio (AR<3dB). Finally this antenna is able to steer in elevation to $45°$, $75°$, $105°$ and $135°$ electronically with a Butler matrix network and $360°$ in azimuth with a motorized junction. In [29], a system based in horn antennas and beamforming networks is shown. This antenna is capable of using several beams simultaneously. On the other hand, solutions based in Traveling Wave Antennas (TWA) [30]-[31], allow to control the direction of the radiation pattern as a function of frequency for a narrow band.

## V. Conclusions

During this Short Term Scientific Mission, in IMST under the supervision and guidance of Dr. Marta Martínez-Vázquez a review of metamaterials and active antennas was carried out. The focus of the study was EBG structures and its applications. In future works EBG structures will be applied to reduce mutual coupling between elements in steering applications.

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